ELECTRONIC TRACKING SYSTEM FOR STUDYING THE "OSCILLATORY EFFECT" IN INSECTS

ARS-S-96

April 1976

AGRICULTURAL RESEARCH SERVICE • U.S. DEPARTMENT OF AGRICULTURE

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE
in cooperation with
Mississippi Agricultural and Forestry Experiment Station

CONTENTS

Illustrations

ELECTRONIC TRACKING SYSTEM FOR STUDYING THE "OSCILLATORY EFFECT" IN INSECTS

By J. B. Carlton[1]

ABSTRACT

A voltage amplitude-to-pulse width converter circuit was designed, developed, and tested for tracking the position of single insects suspended in an electric field. The tracking technique was conceived and developed to pursue studies of an insect phenomenon called the "oscillatory effect," a motion that is for the most part a low-frequency, back-and-forth swing produced by an electrostatic interaction between the bioelectric field of the insect and a fixed direct-current field superimposed on it. The tracking system was reliable and suitable for basic studies of the phenomenon in several hundred insects, mostly boll weevils. The oscillatory effect was observed in boll weevils, house flies, and roaches; presumably it also exists in other insects. A considerable amount of variability was observed in the recorded patterns. The results, although not conclusive, support the theory that the phenomenon is caused by respiration.

INTRODUCTION

In developing a method to measure electrostatic charges on the bodies of house flies, I observed a phenomenon that I called the "oscillatory effect."[2] The response, observed when living insects were suspended on small insulating fibers in a direct-current electric field, was a swinging back and forth, apparently in accordance with some biological process. The effect ceased after the insect was exposed to lethal fumes.

Efforts to identify the response as respiratory were not completely successful. One physical explanation suggested by the method used is that the insect emits ions of one predominant polarity at some given instant. Then the electric field of the charge that remains on the insect interacts with the electric field in which it is suspended, producing a deflection. Later, the same process is repeated, but with opposite polarity. Such a process would account for the observed response.

Objects suspended in an electric field experience an induced dipole that might have some bearing upon the results. The induced dipole, over which the insect has considerable control, may initiate the observed effect. The process (physical and biological) is not entirely physical, however, since the induced dipole elicits no response after the death of the insect. I also found some evidence that the sex of the insect may be a factor in the amplitude of the oscillatory response. In the mass rearing of insects for research uses, there is a need for rapid, nonsubjective sex identification techniques. Consequently, further study of this bioelectric phenomenon would be justified to determine the feasibility of its use to distinguish sex.

The earlier experimental system provided a means for tracking insects by suspending them from a small insulating fiber between two parallel metal plates to which 15,000 volts was applied. The plates were ¾-centimeter-thick aluminum squares, 50 centimeters on an edge. They were mounted vertically on a rigid table, with a 12-centimeter air gap between them. A movable-base telescope was mounted on one end of the table so that the space between the plates could be observed. The tele-

[1]Formerly, research agricultural engineer, Boll Weevil Research Laboratory, Agricultural Research Service, Mississippi State, Miss. Present address: Agricultural Research Service, Department of Agricultural Engineering, Texas A&M University, College Station, Tex. 77843.

[2]Carlton, J. B. 1971. The quantitative measurement of an electrostatic charge on a house fly by capacitor techniques. 113 pp. Ph. D. dissertation. Texas A&M University, College Station.

scope operator could readjust the position of the telescope as needed to follow the lateral motion of a suspended insect. A position transducer was connected to the base of the telescope. The initial location of the insect's body (geometrically centered between the two plates) was taken as the neutral, or no-charge, reference point. When 15 kilovolts dc was applied to the plates, the insect began to move laterally. Depending upon the plate-voltage polarity, the insect's movement relative to the starting point established the polarity of the insect's body charge. The amplitude of deflection was directly related to the insect's body charge. The setup was essentially a remote-sensing (passive system) device that sensed the magnitude and polarity of the body charge.

Mechanical tracking by an operator was tedious, boring, and somewhat subjective. Pursuit of this research required better methods of study and observation—in particular, an electronically controlled optical tracking system. Thus, the objectives of this work were to design and develop a voltage amplitude-to-pulse width converter circuit to monitor and track the horizontal component of the insect's motion in the electric field and to determine the system's reliability and the kind of recorded information obtainable from selected insects.

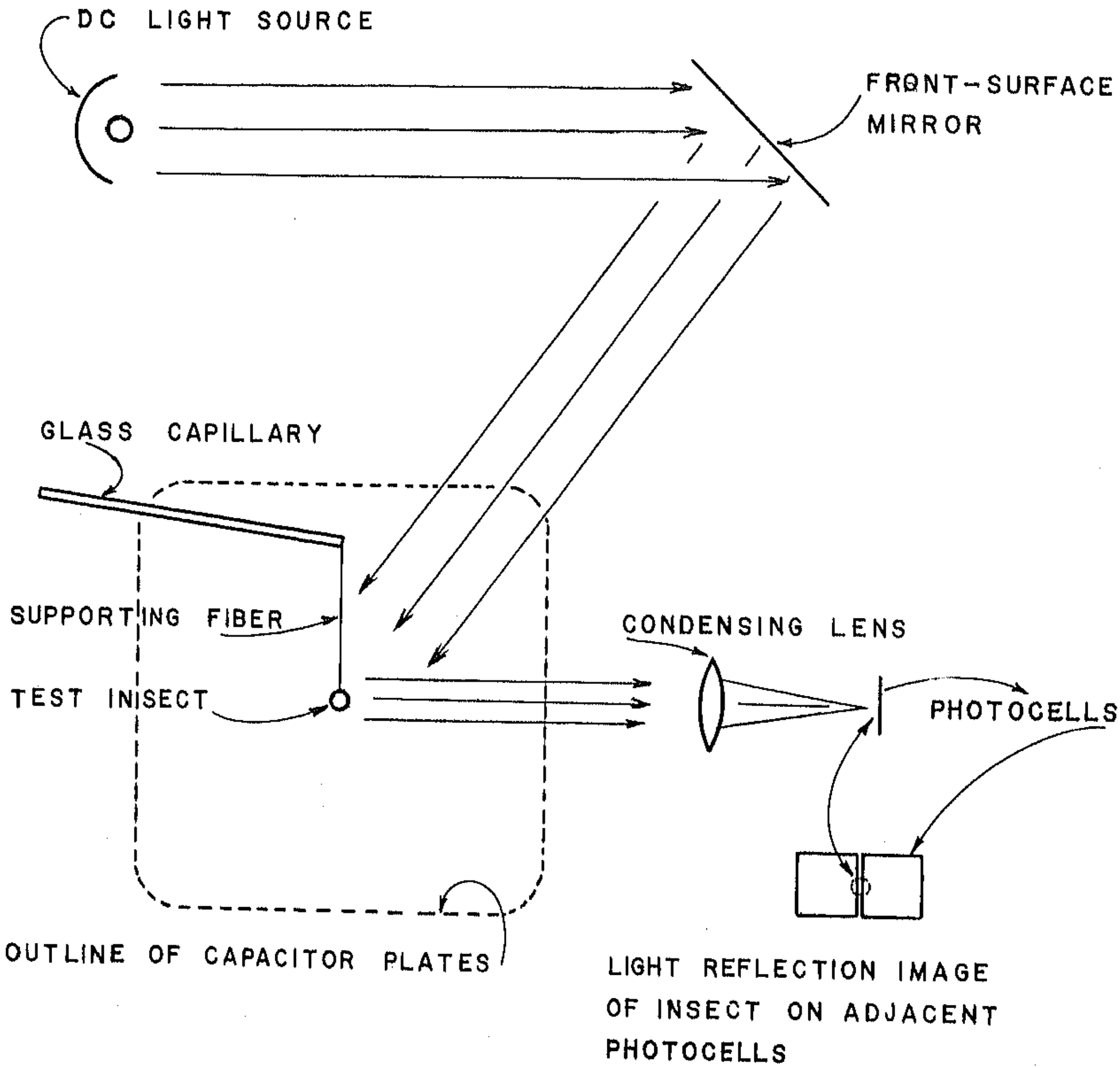


FIGURE 1.—Schematic of insect-tracking system.

SYSTEM DESIGN AND OPERATION

Requisites for the system were as follows: electrooptical tracking; continuous monitoring capability, to allow overnight operation; a sensitive circuit, because low light levels would be required to prevent overheating of insects and because dark-colored insects reflect little light; readout by a strip chart recorder; and circuit stability, to give repeatable and accurate results. The general operational concepts are illustrated in figure 1. A collimated light source is reflected by a mirror between two parallel high-voltage plates. The light impinges upon the test insect and completely illuminates the region within which it is free to move. (Wings are glued together so that it does not fly.) Light reflected from the insect is collected and focused by the condensing lens upon two adjacent photocells. The lens and photocells are mounted on a common support that fixes their position relative to each other. A servo motor rotates the support through the geometric center of the vertical axis of the lens. As the insect moves laterally (because of a change in its electrostatic body charge), the focused light beam is deflected from the center of the adjacent photocells, unbalancing their output signal. Routed through an electronic circuit, the unbalanced signal drives the servo motor, rotating the lens and photocells in a direction that again repositions the focused light image equally between the adjacent photocells.

Because of availability and low cost, a small digital proportioning servo (used in radio-controlled model airplanes) is used as the positioning device. A circuit (figs. 2 and 3) incorporating this servo senses the linear (or analog) change in the position of the insect and converts the information into a pulse width to control the servo and cause it to move in the proper direction. An astable multivibrator with a variable output amplitude control controls the output pulse width of a monostable timer whose output is fed to the servo.

To vary the pulse width, an analog circuit was constructed according to figure 3. High-quality solar cells are used as detectors at the input of the direct-current amplifier. The solar cells are connected so that if the light image falls on one cell, a positive voltage appears at the input of the direct-current amplifier, and if the image falls on the other cell, a negative voltage appears at the input. An image centered between the cells yields zero voltage output, which is the condition that the servo must seek to maintain for proper operation of the tracking system.

The output voltage from the solar cells is quite small (10–20 microvolts) and has to be amplified considerably; for this purpose an operational amplifier (μA725) is used to provide a voltage gain of 100 to 1,000 from the solar cell source. When using this amplifier in such a high-gain circuit, the offset voltage becomes a problem. (Offset voltage is the voltage that appears at the output of the amplifier when the input is grounded.) The circuit

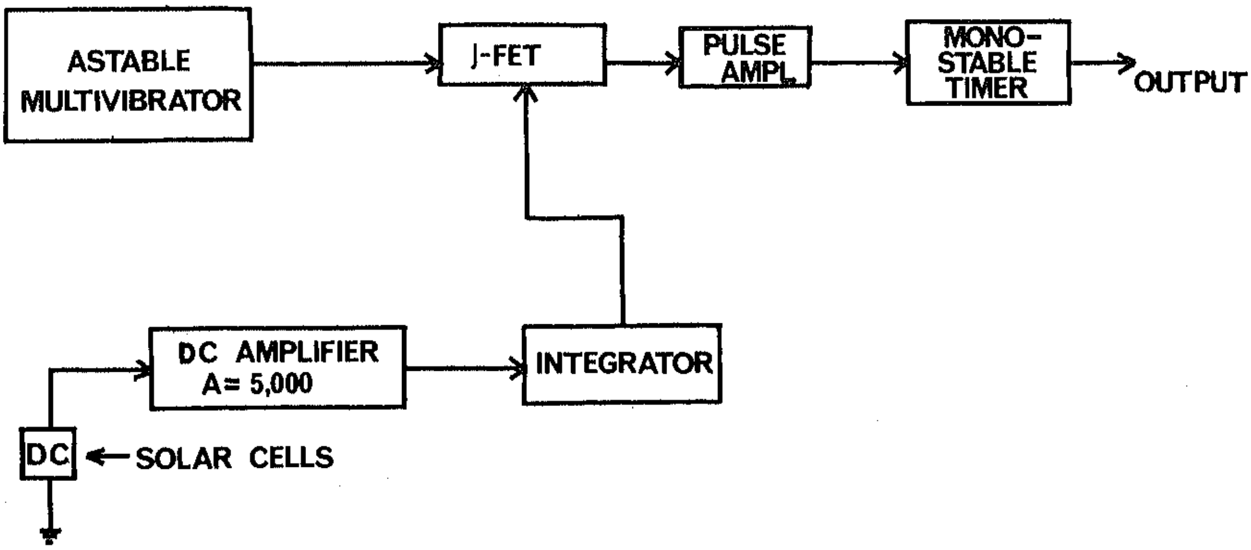
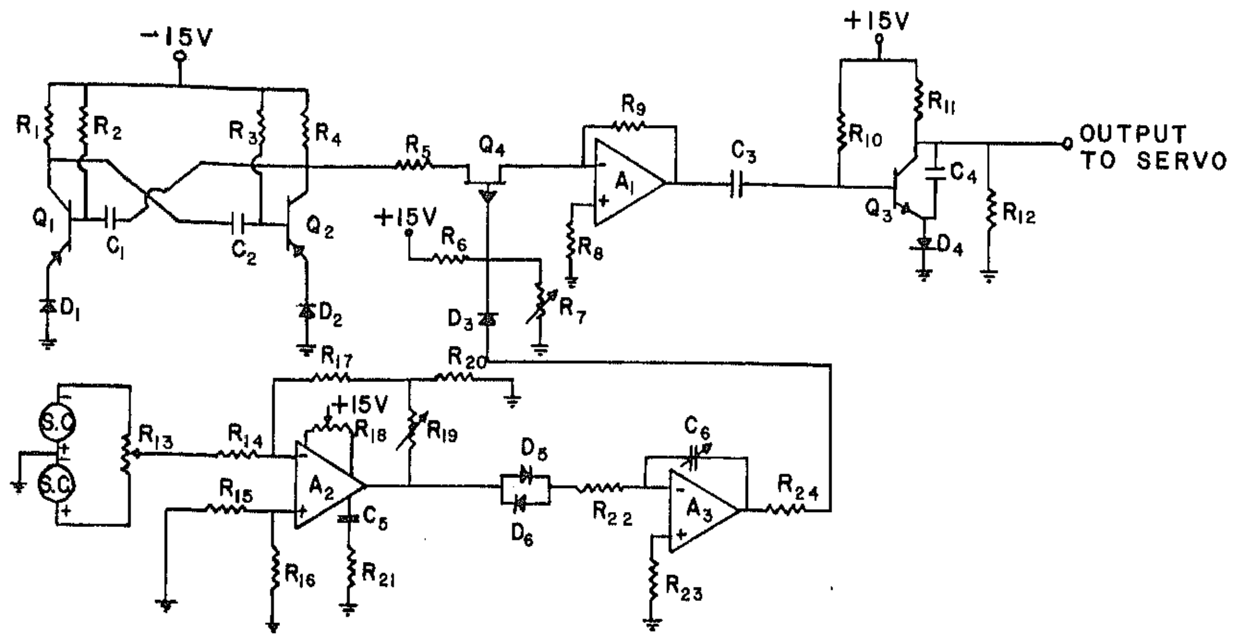


FIGURE 2.—Block diagram of voltage amplitude-to-pulse width tracking circuit.



Resistors:

- R_1, R_4, R_{21}=470 Ω (ohms)
- R_2, R_3=27 kΩ (kilohms)
- R_5, R_{20}=10 kΩ
- R_6, R_{10}=100 kΩ
- R_7, R_{19}=100 kΩ (trimmer)
- R_8, R_{23}=1 kΩ
- R_9, R_{11}, R_{12}, R_{24}=4.7 kΩ
- R_{13}=1-kΩ potentiometer
- R_{14}, R_{15}=500 kΩ, 1%
- R_{16}, R_{17}=50 MΩ (megohm), 1%
- R_{18},=100 kΩ (precision potentiometer)
- R_{22}=47 kΩ

Capacitors:

- C_1, C_2=0.33 μF (microfarad)
- C_3=0.047 μF
- C_4=0.001 μF
- C_5=100 pF (picofarad)
- C_6=Capacitor switch
  1. 10 μF
  2. 6 μF
  3. 4 μF
  4. 2 μF
  5. 0.22 μF
  6. 0.1 μF

Diodes, small signal type:

- D_1, D_2, D_3, D_4=silicon
- D_5, D_6=germanium

Transistors:

- Q_1, Q_2=type 2N2605
- Q_3=type 2N2270
- Q_4=P-channel J-FET (2N4360)

Operational amplifiers:

- A_1, A_3=741 C
- A_2=725 (precision)

Solar cells:

- S.C.=110 CL (blue cells), Central Lab

FIGURE 3.—Schematic diagram of voltage amplitude-to-pulse width tracking circuit.

provides for counteracting the offset voltage by shunting the input so that the output can be zeroed.

The voltage that appears at the output of the direct-current amplifier section is of sufficient magnitude to be used by the integrator. In testing the circuit, some high-frequency noise was evident in the signal. This noise was caused primarily by the operational amplifier and the very large gain of the direct-current amplifier being used. However, since the noise had a magnitude of only about 0.2 volt, a pair of silicon diodes placed back to back (fig. 3) very satisfactorily prevent the noise from being applied to the integrator and causing drift.

A ramp function is generated when the output of the direct-current amplifier is integrated. (Refer to figure 3 concerning circuit description.) When the input to the integrator is zero, it stops integrating and holds a constant output voltage, either positive or negative, until some input signal causes the output to change value.

The output from the integrator is applied to the gate of a P-channel, J-FET. A diode in series with the integrator output prevents the J-FET from becoming forward biased when the output from the integrator becomes negative. A pair of bias resistors on the gate of the J-FET set the quiescent operating point. (In this circuit, the J-FET is used as a voltage-variable resistor; thus, the voltage applied to the gate will control the pulse amplitude that is passed through the J-FET from the astable multivibrator to the monostable timer. The more positive the voltage applied to the gate of the J-FET, the smaller the pulse amplitude passed by the device.)

The astable multivibrator operates at a constant frequency of 160 hertz and has an output amplitude

of about −14 volts. This frequency was chosen because of the pulse width requirements of the servo.

The output of the astable multivibrator is fed to an inverting amplifier whose gain is controlled by the J-FET. This configuration serves two purposes: first, it isolates the output of the astable multivibrator from the monostable timer, providing a low-impedance output; and second, it inverts the negative pulse that appears at its input so that a positive pulse appears at the output of the amplifier. The positive pulse charges the input capacitor of the monostable timer to a voltage level determined by the control signal on the J-FET. The negative-going transition at the end of the positive pulse places a negative voltage on the base of the timer transistor, which turns it off. The width of the output pulse from this circuit is controlled by the amplitude of the input wave and the time constant of the input capacitor and the base bias resistor.

The output pulse must be positive, about 5 volts, and smoothly variable between a minimum of 1 millisecond and a maximum of 2 milliseconds for proper control of the servo. Thus, the bias adjustment on the gate of the J-FET easily controls the limit on pulse width and assures proper servo control.

In summary the solar cells are the sensors for the system, and it is the direct-current output from these cells that must be converted into pulse-width information for the servo. The output from the solar cells is amplified and applied to the integrator. The output from the integrator then changes the bias on the J-FET, which in turn controls the pulse amplitude that passes from the astable multivibrator to the monostable timer. This change in amplitude causes a corresponding change in the pulse width that appears at the output of the monostable timer, and thus controls the servo.

Figure 3 does not show the remainder of the circuit to the servo, power supply, or recorder. The power supply for the circuit is a standard ±15-volt source. The servo power supply is a unit supplied with the servo. The recorder circuit is provided by applying ±15 volts to a precision servo potentiometer (100 kilohms plus two trimmer resistors on each side of the potentiometer for recorder range adjustment) attached to the rotating shaft that supports the lens and solar cells.

Figure 4 shows the assembled apparatus containing the components shown in figure 1. The components of the tracking circuit are enclosed in the box positioned before the capacitor plates (see arrow, fig. 4). In operation, the tracker and parallel plate system are electrically shielded by a copper wire enclosure covered with a black plastic film to seal out light. For a complete description of all other components of the system and the associated variables for the items in figure 4, see reference cited in footnote 2.

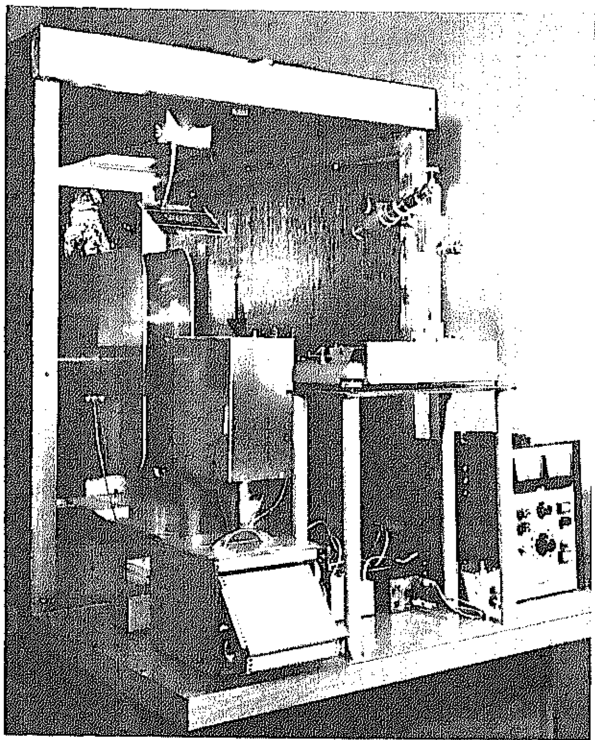


FIGURE 4.—Assembled tracking system.

TEST RESULTS

Test insects were suspended by nylon fiber, 20 micrometers in diameter, 10 centimeters from the end of the supporting glass capillary rod. The apparatus was successfully used to monitor the oscillatory response of insects for 6 months, with only a few system problems. The noise level in the recorded output was about 2 percent. The movement of the test insect's legs, without body movement, accounted for some of this noise. However, the varying contact resistance of the servo potentiometer providing output to the recorder contributed most of the noise.

Figure 5 illustrates the oscillatory response of a house fly, *Musca domestica* L. The horizontal time-scale axis corresponds to the neutral, or no-charge, position (Q=zero) of the insect's body. As the insect moves so that the graph is above the Q=zero axis (i.e., in the $+Q$ region), a positive body charge is borne by the insect. Upon release of this positive charge, the insect swings to the minus Q

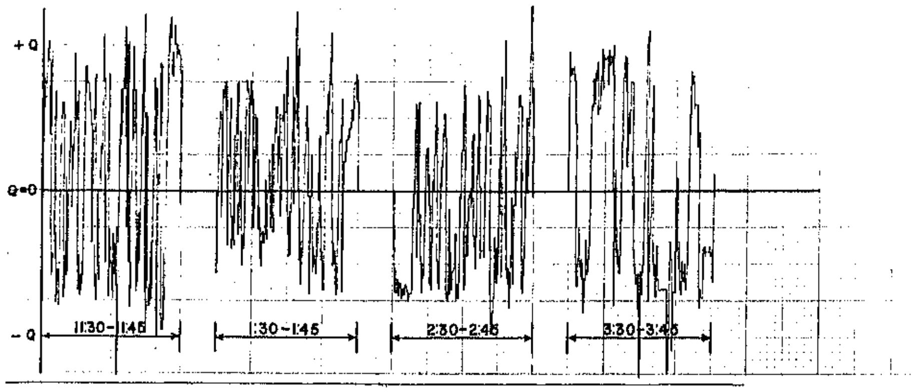


FIGURE 5.—Oscillatory response of a house fly during 15-minute intervals.

region, bearing a negative charge. Figure 6 shows similar tests for a male and female house fly before and immediately after exposure to lethal fumes. (In all recorder figures, full scale on the chart paper represents 12 centimeters.) These graphs provide an indication of the amount of lateral insect swing in the electric field.

Several hundred boll weevils, *Anthonomus grandis* Boheman, were monitored continuously during 30-minute intervals. Figure 7 shows the graphs produced by two male and two female weevils monitored continuously for 1 hour. The amplitude responses varied considerably as compared to those of the flies in figure 6. A few American cockroaches, *Periplaneta americana* (L.), less than 15 millimeters long, produced results similar to those observed for flies and boll weevils.

The electronic tracking circuit proved to be quite reliable for the purpose intended. Although the objectives of this research did not include a rigorous study of the oscillatory effect, the results obtained indicate that further study of this effect is desirable. Since the oscillatory effect was found to exist in all three insect species studied, it probably exists for

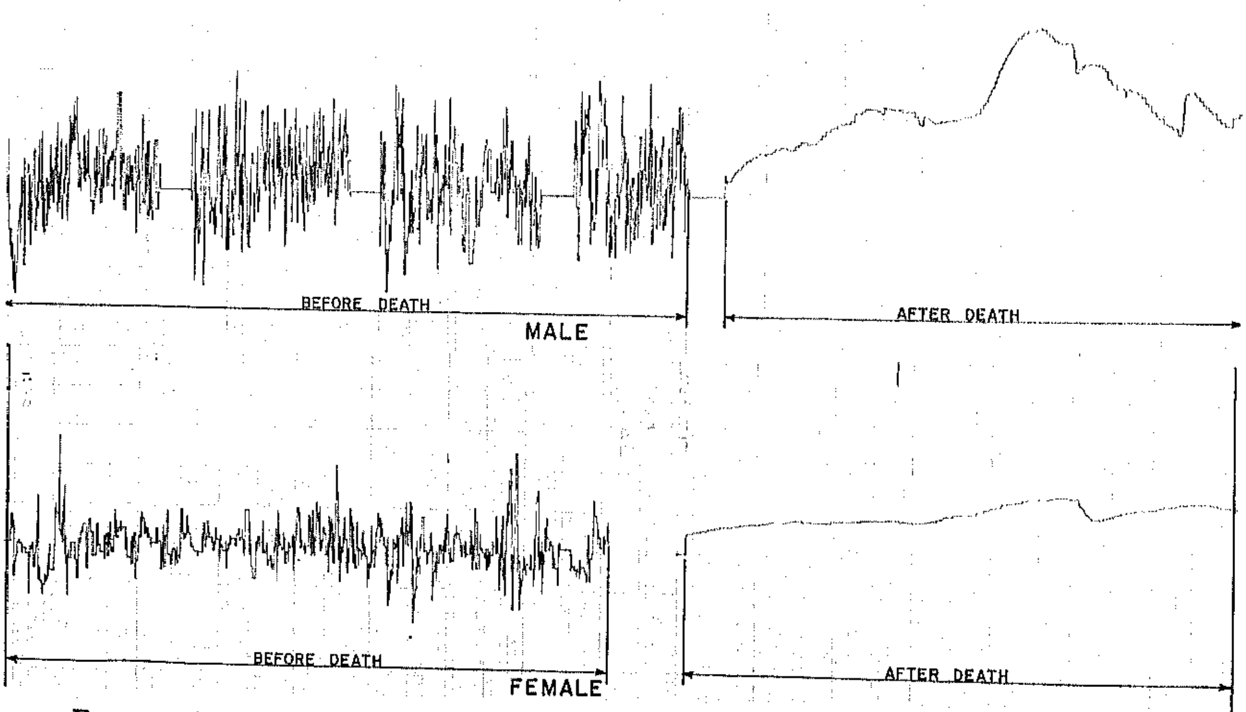


FIGURE 6.—Before-death and after-death electrical responses of male and female house flies.

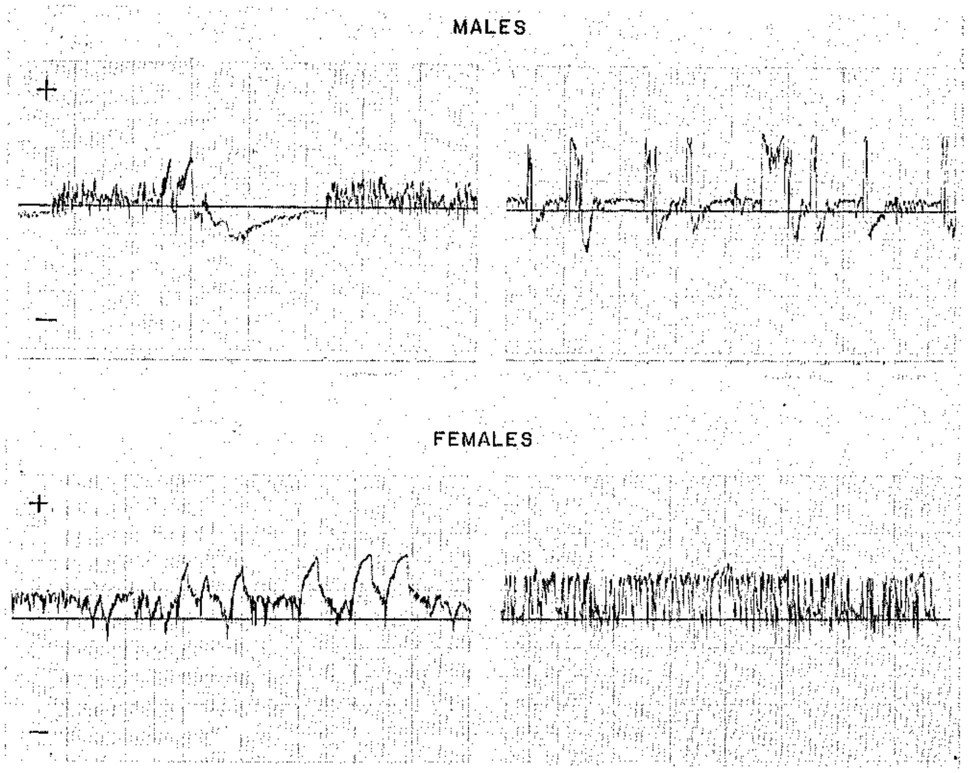


FIGURE 7.—Continuous 1-hour response of two male and two female boll weevils.

other insects. The recorder charts displayed a considerable amount of randomness. There is evidence that the effect may be time dependent. When the physics of the process is considered, such evidence is not surprising. That is, the various deflections could result from an interaction of the insect's bioelectric field (which exists exterior to the insect's body) with the electric field in which it is immersed. As various biological processes change internally with time, the associated biopotentials change; hence, the bioelectric fields change. Alternatively, if the effect is brought about by an ion-exchange process, the insect's surface electrostatic field would interact with the experimental electric field. Such interaction would lead to the observed effects. Over much shorter periods of time, as indicated from the recordings, the general response of the insect is like that of an oscillator or alternating generator—generating first a positive voltage, then a negative voltage.

*1976-G.P.O.-1750-S/671-583/48